

## **A comparison of survival strategies in the extreme environment**

Species living on the Antarctic continent and its surrounding oceans have had to adapt to live in the extreme environment. These adaptations are specialised strategies that species have evolved to aid survival by increasing reproductive success and lifespan of the individual and have occurred over geological time frame. These survival strategies fall into three main categories, which are biochemical changes, physiological changes and behavioural changes. Biochemical changes are those that occur at a cellular or protein level, or chemical processes. An example of this is the polypeptides of antifreeze glycoproteins and antifreeze peptides of notothenioid fish such as *Pagothenia borchgrevinki*. Physiological changes are changes to the structure of a species to help the species function more efficiently. These are generally larger in scale and can be measured or observed, such as the Antarctic krill *Euphausia superba* retaining the ability to moult into adulthood in response to food supply. Behavioural changes such as the migration of Adélie penguins *Pygoscelis adeliae* in the winter months show conscious movement to a northern location where the chances of survival are increased. There are many survival strategies in Antarctica and most species have a combination of the different types. The aim of this review was to choose one adaptation within different groups of organisms to demonstrate the range of survival strategies, using one species as an example of each. Scientific journal articles, Antarctic organisation websites and published books were used.

Antarctica is an extreme environment due to its isolation and circumpolar currents, and is a stable cold polar region. The continent ranges in temperature from around +15°C on the Antarctic Peninsula, to the coldest temperature recorded at Vostok in July 1983 at -89.6°C (Antarctica NZ Website, 2006), with typical coastal winter temperatures between -10°C and -30°C, and inland temperatures around -60°C due to increased elevation, latitude and distance from the ocean (BAS website, 2006). The ocean is a constant -1.9°C with minute ice crystals present in the water at decreased depths, and has a lower freezing point due to the salinity of the water (Ahlgren et al, 1988; Jin and DeVries, 2006). Almost 98% of the continent is covered by ice (McGonigal and Woodworth, 2002) and the ice-free areas are

competed for. Combining these weather conditions with the windy, arid conditions, create a very harsh environment to live in. As a result, the largest terrestrial animal found on the continent is the wingless midge *Belgica Antarctica*, with most organisms remaining in Antarctica over winter living under the sea ice, where the sea temperature is warmer than the air temperature, and all organisms having specialised strategies.

### **Antarctic Krill - *Euphausia superba***

Krill are euphausiids, and are shrimp-like filter-feeding crustaceans that form large swarms. They are predominantly herbivorous and feed on phytoplankton, although some species are omnivorous or fully carnivorous (Everson, 2000). Antarctic krill, *Euphausia superba*, are one of seven species found in Antarctic waters and have considerable media and scientific interest due to the commercial fishery for aquaculture feed, bait, pet food, human consumption and pharmaceutical products. This species is the focus of this section. The other major Antarctic species is the smaller ice krill *Euphausia crystallorophias* which lives much deeper at around 300-600 metres depth and much less is known about. Other krill species known in the Southern Ocean are *E. frigida*, *E. longirostris*, *E. triacantha*, *E. vallentini*, and *Thysanoessa macrura* (Everson, 2000).

Antarctic krill are extremely abundant with biomass estimates ranging from 125 to 750 tonnes in 1985, and now thought to be between 90 million tonnes and 7 billion tonnes. However, more recent studies show krill biomass is likely to be at the lower end of this range, between 90 and 155 million tonnes. This range is large due to differences in the spatial and temporal variation in krill distribution and the methods used to estimate the biomass (FAO Website, 2004). Antarctic krill are generally smaller than 60 millimetres in length (Alonzo and Mangel, 2001). They have a wide geographic distribution and are found throughout the oceans between the polar front and the Antarctic continent. Krill are at the centre of the Southern Ocean food web. Squid, fish, birds, fur seals, leopard seals, crabeater seals and baleen whales are all dependent on krill as a direct food source, and many of these also eat krill indirectly through consumption of squid and fish (Everson, 2000).

The current major problem faced in krill fisheries and research is measuring population abundance and working out parameters for fisheries models such as total allowable catches and biomass models. This has been a problem due to the physiological adaptation of krill retaining the ability to moult into adulthood (Daly, 2004). This allows krill to adjust their size based on available food supplies, particularly during winter months. In periods of large amounts of food present, the krill will continue to eat and grow before moulting into a larger exoskeleton. In periods of low food availability, the krill will use its own protein as a food supply and this will reduce their size and moult into a smaller exoskeleton. However, the extent to which krill can reduce their body size has been debated (Daly, 2004).

Krill growth is dependent on environmental conditions, their habitat and food availability, and is dependent on the difference between their metabolic costs and feeding rate (Alonzo and Mangel, 2001). They do not build up fat reserves like many other marine species to use as food reserves, but lipid reserves can be used during low food supply. This physiological adaptation for krill species to moult throughout the year, and particularly over winter, is important for survival, as survival will be related to its body size, weight, and composition including lipid and protein storage. Generally, individuals that are larger at the start of winter will have more food reserves available to them, and therefore have a higher chance of survival than smaller sized individuals (Daly, 2004). Cold temperatures are also thought to cause shrinkage forcing them to moult. Cold temperatures slow growth by slowing feeding rates and increasing metabolic costs, with a greater effect on larger sized krill that have higher energy demands (Alonzo and Mangel, 2001).

Many scientists have tried to create models to predict krill biomass and fisheries models to estimate what level of total allowable catch is sustainable, as the level of fishing intensity will increase as technology increases to overcome problems such as high fluoride concentrations within the carapace from spoiling the meat. A model created by Suzanne Alonzo and Marc Mangel (2001) predicted that krill shrink under both positive and negative energy budgets, relating to metabolic cost in relation to food intake and therefore energy. They state that krill shrink under negative energy budgets in response to decreased food supply, and also by extreme temperature conditions. This model is based on

knowledge of krill physiology and environmental conditions from previous research. A new prediction they make is that krill also shrink in response to predator risk under positive energy budgets, and not solely due to lack of food. They state that predation is size dependent and larger individuals are more at risk than smaller ones, and this risk is related to habitat and growth. This could explain why krill continue to moult through summer and during periods when food is abundant, but further research is required to substantiate this prediction. Alonzo and Mangel state that research should particularly look into the effects of predators at depth and those other than land based and diving mammals, which have been previously studied (2001).

Most of the current literature surrounding krill has focused on their geographical distribution, and designing fisheries models to determine sustainable limits. The increase in krill fishing is shown below in figure 1 based on Food and Agriculture Organization of the United Nations (FAO) statistics. This graph shows a large increase in krill fishing throughout the 1980's with a sharp decrease in 1984 and another in 1994, with maintained levels after this. There are many uses for krill products including direct human consumption, animal feeds, aquaculture feeds, pharmaceutical products and sport fishing bait.

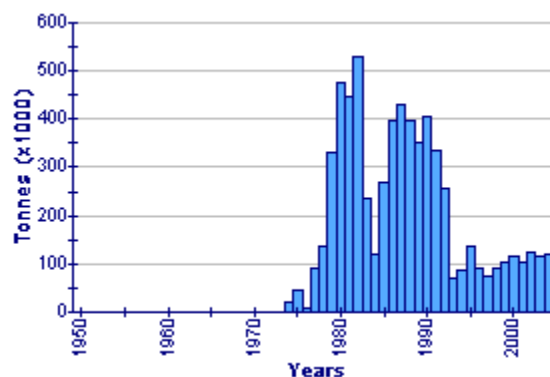


Figure 1: Graph showing the Global Capture production for *Euphausia superba* (Fao Fishery Statistic)

Source: <http://www.fao.org/figis/servlet/species?fid=3393>

Research is also currently focused on growth models, finding alternative methods to estimate age of krill, and uses of krill products. Age estimation is an area of research that should be focused on, as age determination is an important parameter for fisheries modelling and as the need for fishmeal for aquaculture and other potential uses of krill

increases. It is important that adequate krill stocks are maintained for other species that depend on it in the Southern Ocean food web. FAO state that “It is nevertheless accepted that the scientific basis for management of this fishery is weak and further information on the behaviour of this species and fishing statistics are badly needed” (2004).

**Notothenioid fish. E.g. *Pagothenia borchgrevinki***

Antifreeze glycoproteins (AFGP) and antifreeze peptides (AFP) have had considerable interest since discovery in the Antarctic notothenioid fish in 1968 by Arthur DeVries. Arthur DeVries has continued to study these proteins and has contributed significantly to this area, and is cited in almost every AFGP journal article and book. Another major contributor is Chi-Hing Cheng. AF(G)P's were thought to be a unique adaptation to Antarctic polar regions but have since been found in both temperate species in New Zealand showing common ancestry (Cheng et al, 2003), and arctic species through convergent evolution (Fletcher et al, 2001).

Most fish body fluids have a freezing point below 0°C due to the salt content within the fluid, with NaCl as the major salt source with smaller amounts of potassium, calcium, urea, glucose and amino acids (DeVries and Cheng, 1992, Eastman, 1993). This fluid freezes at -0.9°C in temperate fish. As the water temperature is below this at around -1.9°C (Jin and DeVries, 2006), other controls are needed to prevent freezing. The cold water temperature is not lethal, but the minute ice crystals present in the water column can be. However, ice crystals can be present internally without being fatal (Fletcher et al, 2001). These enter the fish through the mouth, or surface tissues such as the gills and skin, and provide a framework for more ice crystals to grow. This ice entry is not frequent. Some fish live in deeper water where no minute ice crystals are present and live in a supercooled state, while others use AFGP's to prevent this build-up of ice crystals. It is not possible to be supercooled in the presence of ice crystals (DeVries and Cheng, 1992). Notothenioid fish in McMurdo Sound have a freezing point of around -2.2°C, and seawater here freezes at -1.91°C (Eastman, 1993) showing the body fluids are sufficiently able to resist freezing.

Antifreeze glycoproteins are not found intracellularly except for within the liver cells where synthesis occurs, before being secreted into the blood and transported to other fluid compartments (Alghren et al, 1988). This process occurs by passive diffusion. Secreted fluids such as urine do not contain antifreeze compounds and this is because no filtration occurs in the kidneys in urine formation (DeVries and Cheng, 1992). The freezing point of urine remains below zero due to ion content, but would freeze in the presence of ice crystals. This is avoided by having a large muscular sphincter acting as a physical barrier. It is since been suggested that a separate family on AFGP's is found on the skin and in the gills to prevent the tissues from direct contact with ice. They also suggest that these proteins interact with cell membranes and prevent damage, but these require further research to be validated (Fletcher et al, 2001).

There are eight different antifreeze glycoproteins that have been isolated in *Pagothenia borchgrevinki* and vary in size and structure. They are numbered 1 to 8, with 1 being the largest in size with 34,000 daltons, and size 8 the smallest having 2600 daltons. In general terms, sizes 1-5 are classes as large AFGP's, and 6-8 are classed as small. More sizes have been found in other species, but are within this molecular weight range (DeVries and Cheng, 1992). The small sized AFGP's are more abundant in all species and have less antifreeze activity showing weaker inhibition of ice crystal growth than the larger sized molecules, showing a positive correlation of activity and size. There is also a positive correlation between concentration of AFGP's and activity. Antifreeze glycoproteins and peptides consist of a glycotriptide repeat of alanyl-alanyl-threonine with a disaccharide sugar group N-acetylgalactosamine and galactose linked to the threonine molecule with a glycosidic linkage (DeVries and Cheng, 1992; Eastman, 1993). AFGP occur at a concentration of 35 mg/ml (3.5%) in notothenioid fish blood and slightly lower in body fluids (Eastman, 1993).

Antifreeze glycoproteins work in a non-colligative by depressing the freezing point but not the melting point as shown below in figure 2 (page 7). AFGP's work by the process of adsorption-inhibition as first described by Raymond and DeVries in 1977. The antifreeze binds to the minute ice crystals to inhibit further growth by hydrogen bonding in a lattice

structure. This ice binding is non reversible (Fletcher et al, 2001). There are two hypotheses for how the process of binding occurs. One is via hydrogen bonds and the second is via hydrophobic bonds. (Fletcher et al, 2001). It is thought hydrogen bonds are used and join the hydroxyl and amino groups of AFGP to the oxygen atoms of the ice lattice (Eastman, 1993). Once AFP's have bound to ice crystals, the ice crystals must be removed from the system. One hypothesis is that they accumulate in the spleen and 'melt out' when external temperatures are warmer

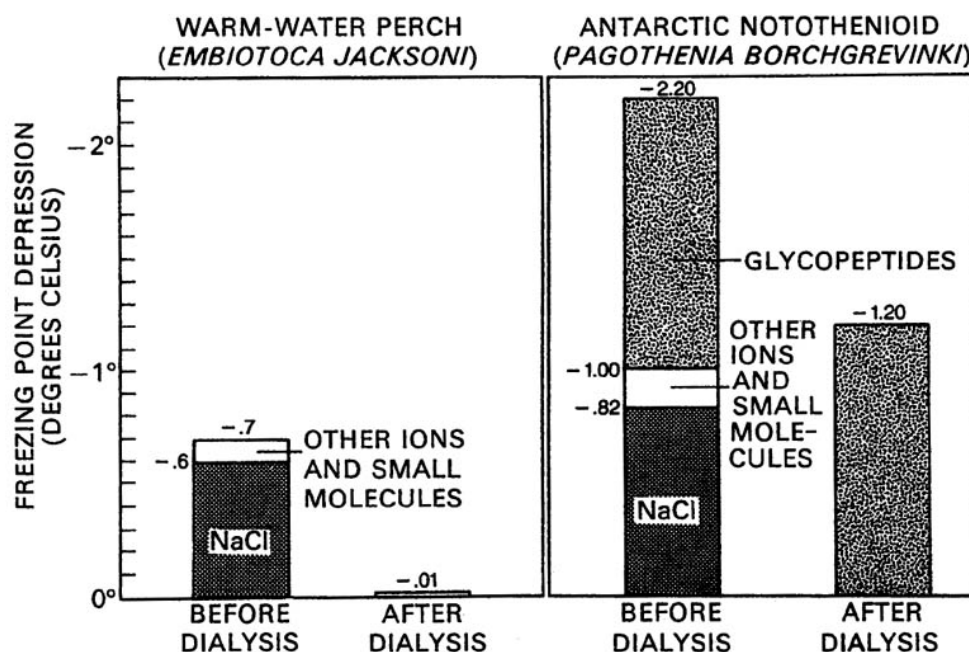


Figure 2: Diagram of how AFGP contribute to depressing the freezing point, and the abundance of molecules within the fluid Source: Eastman, 1993

Antifreeze glycoproteins evolved from a trypsinogen-like protease gene for a digestive enzyme (Cheng and Chen, 1999). A study by Cheng et al in 2003 showed some New Zealand temperate fish species have the gene for antifreeze and this infers an evolutionary relationship, but the origin of these temperate-water nototheniids is not completely understood. It is most likely the AFGP gene evolved between 5 and 15 million years ago and this can be used to infer evolutionary relationships. The gene was found in some ancestors, *Notothenia angustata* and *Notothenia microlepidota*, but not in *Bovichthus variegatus*, which has been used to create a tree showing divergences (Cheng et al, 2003).

This would indicate the AFGP's are not a unique adaptation to the cold polar environment. They have also been found in Arctic fish species with very similar structure, showing convergent evolution has occurred.

Initial interest was in which species had these antifreeze proteins and how they worked, and now the research focus is in its molecular structure and genetic basis, evolution and potential uses in agriculture and medicine. As the awareness of global warming increases, more papers like di Prisco and Verde's paper on predicting the impacts of climate change on the evolutionary adaptations of polar fish will be released (2006).

### **Adélie penguins - *Pygoscelis adeliae***

The third type of survival strategy is related to behavioural changes, where individuals move to warmer climates. Adélie penguins have many adaptations to the cold harsh environment found in Antarctica, which have been studied for many years. These include a layer of subdermal fat to maintain body heat, a streamlined body to maximise energy use when diving and overlapping waterproof, windproof feathers to trap insulating air (Clark, 1998). They also have counter current heat exchange mechanisms in their feet and flippers to minimise heat loss when cold and increase heat loss on warmer days. However, when winter sets in these adaptations are not enough to survive the cold air temperatures, and must migrate as they cannot spend most of their time under the ice like seals where it is warmer. The northern migration of Adélie penguins in the winter months increases their chances of survival.

The breeding biology and physiology of Adélie penguins are well studied. However, less is known and published about where the penguins go in winter, most likely due to the difficulties in tracking penguins in the dark months and the costs involved. Adélie penguins have a breeding range around the shores of the Antarctic continent (Trivelpiece and Trivelpiece, 1990), and most remain south of the Antarctic Circle at 66° 33'S during winter, although some may move onto the pack ice up to 55-60°S (Cockrem, 1990).

The timing that migratory penguin species, including the Adélie, depart and arrive from the continent have been well recorded, from diaries kept by early explorers to recent over



wintering scientists. The timing of migration needs to be precise due to the schedule the penguins follow for breeding during the summer. Early arrivers have more options for nest sites, better mating opportunities and a higher chance of successful breeding (Ainley et al, 1983), and arrive at the rookery in early October. As summer is only three to four months depending on the latitude, breeding must be well timed with both season and partners, to ensure migration can occur at the right time before winter (Trivelpiece and Trivelpiece, 1990).

This migration occurs twice a year from the winter feeding grounds on the northern pack ice to summer breeding grounds on the continent in spring, and back to the winter feeding grounds in autumn. The penguins travel of hundreds of kilometers, showing some kind of distance orientation cue is needed. Many studies in the 1960's have shown penguins can orientate using sun azimuth angles where azimuth is the angle of the sun above the horizon, showing photoperiod control. This requires knowledge about time of day and an internal circadian clock to work out which direction is north based on the time and sun position. It also requires the individual to know its current location relative to a goal (Cockrem, 1990). As the migration is seasonal, a circannual clock would also be required as the penguins would need to know when to migrate to avoid arriving late to breeding grounds or being caught in temperatures and conditions they cannot cope with. Having circadian and circannual endogenous clocks are advantageous in other ways for the Adélie penguin as many other activities are also time controlled. An example of this is the daily movements of krill within the food column. It would be advantageous for the penguins to coordinate their feeding when krill are at the surface of the water to prevent diving for food, and also for coordinating the parenting schedule with their mate (Cockrem, 1990).

Little research has been done on individual migratory Adélie penguins, but some recent satellite telemetry showed some individuals moved 600km to the north of the Ross Sea in winter, and suggest that they move along a common route to pack ice north west of the Balleny Islands (Davis and Renner, 2003). This was concluded after a study during the 1997/98 winter by Davis, Harcourt and Bradshaw, who followed a single Adélie penguin by satellite telemetry. This was compared with the path used by a pair of Adélie's during

the 1990/91 winter. They tentatively conclude that the Adélie penguins follow a common pathway along the coast from Ross Island, past Cape Adare to the Mastusevich glacier before heading north and stopping at the north west of the Balleny Islands as shown below in figure 3. These results are not conclusive as there was an extremely small sample size of a single penguin with a comparison to the movements of a pair from seven seasons before, but is potentially correct (Davis, Harcourt and Bradshaw, 2001). A single penguin was studied due to the large cost associated with using transmitters and having to download the data as it becomes available.

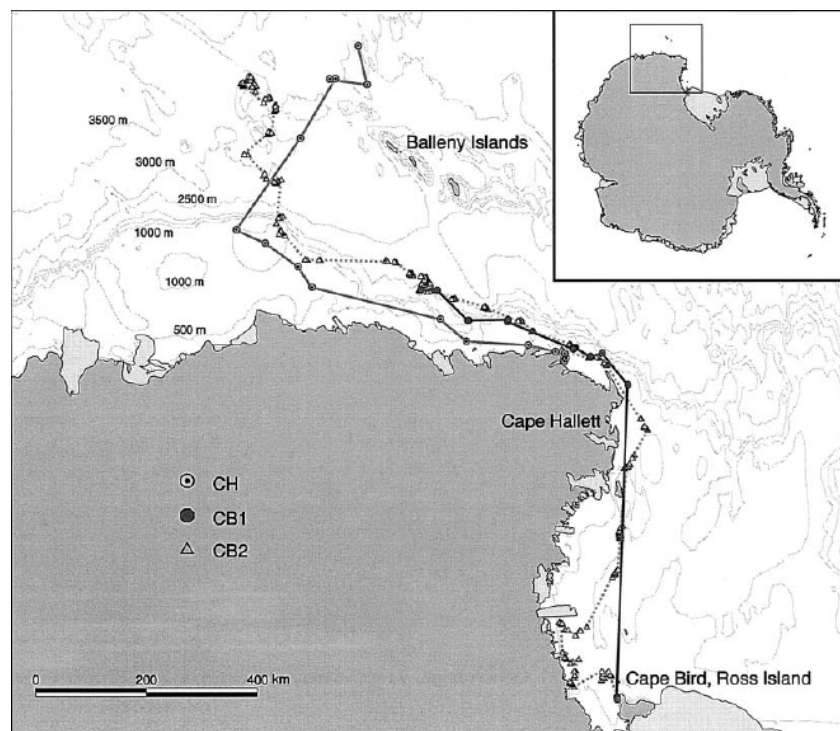


Figure 3: Diagram of Adélie penguin migration (where CH is the Cape Hallett penguin monitored by satellite telemetry and CB1 and CB2 is the pair from Cape Bird used for comparison)

Source: Davis, Harcourt and Bradshaw (2001)

A major problem in the study of Adélie penguin migration is that transmitters become detached before the migration is complete, and caused by feathers falling out of the body rather than the transmitter falling off the feathers. One solution that has been proposed has been to surgically implant a transmitter into the penguin but this is highly invasive. Further research should be undertaken into making transmitters smaller and more reliable,

preferably with an alternative attachment mechanism than the feathers before long term studies commence.

### **Conclusion**

The three survival strategies discussed are not exclusive and most species have a combination of biochemical, physiological and behavioural adaptations to maximise the efficiency at which they live in this harsh environment. The dominant mechanism used will relate to the life history, habitat and lifestyle of that species, and may change over geological time. Many of these adaptations may be unable to cope with the increased sea temperatures or storm frequency that may be associated with global warming, and this is an area of considerable interest. Therefore, while research should continue into the details of these mechanisms, the overall effects should also be looked at, with increasing attention being placed on effects of global warming. Particular emphasis should be placed on whether species will be able to adapt to warmer temperatures, particularly on the Antarctic Peninsula.

**~ 3500 words**

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